A Survey of Possible Methods for Mitigating the Impact of Radio Frequency Interference on Satellite Navigation Systems Used for Precision Approach

James Carroll
Center for Navigation
Volpe National Transportation Systems Center
Cambridge, Mass. USA

April 29, 2004

Background

- Global Navigation Satellite Systems (GNSS)
  - Include GPS, GLONASS, and (soon) Galileo
- Global Positioning System (GPS) – Susceptible to Radiofrequency Interference (RFI)
- Local Area Augmentation System (LAAS) – FAA Augmentation for Precision Approach
- RFI Disruptions of GPS Are a Problem
  - Safety, Economy, Efficiency
  - NOTE: Loss of GPS Ranging Solution Disables LAAS As Well

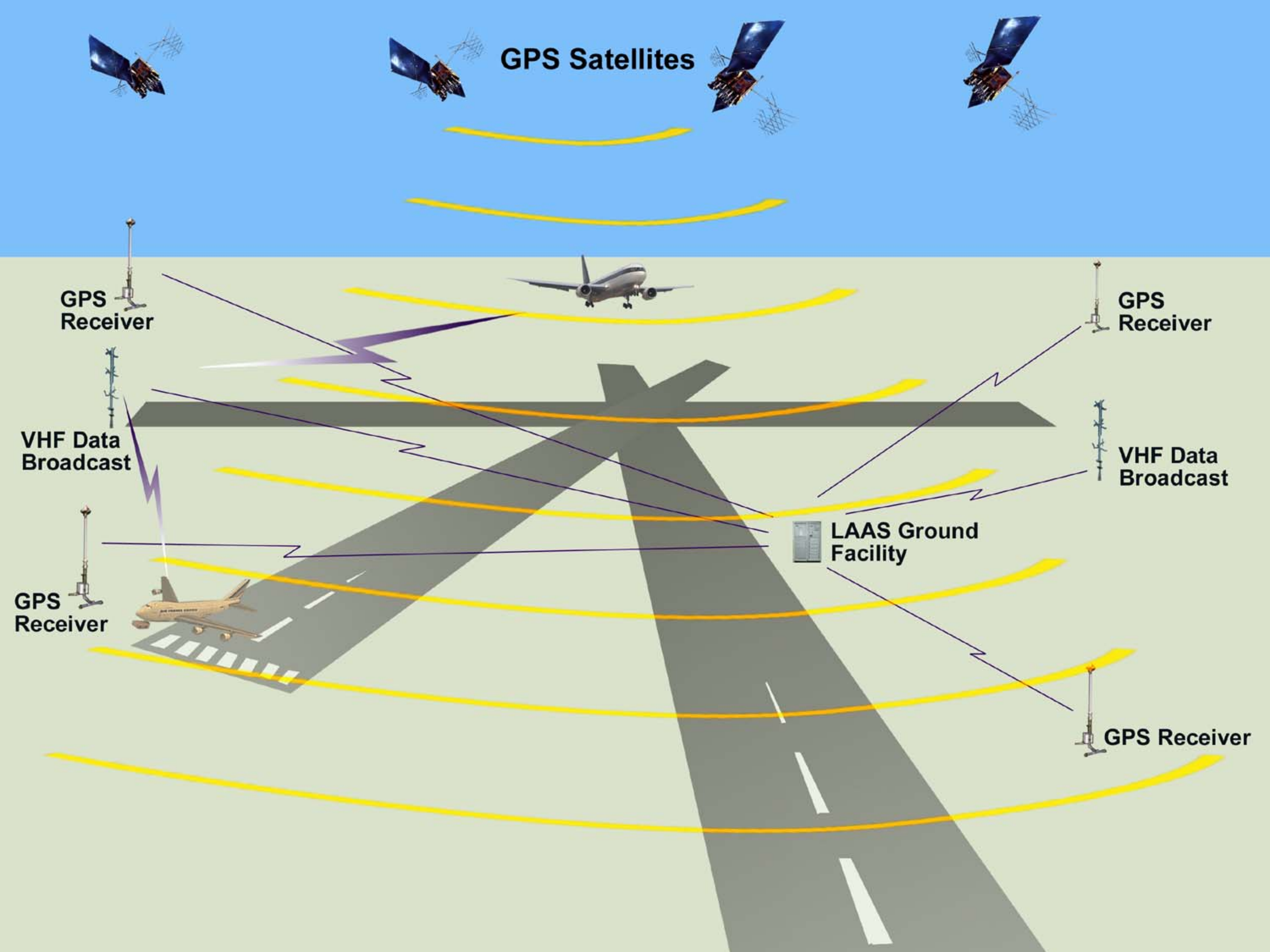

LAAS

RFI Threat

- Intentional – Jamming & Spoofing
  - Sole Means GPS Navigation: Increased Risk
  - Backup Systems and Procedures Marginalize Risk
- Unintentional – Most Likely Cause of RFI
  - Natural Phenomena (e.g., Iono Activity, Multipath)
  - Man-Made Emitters, Spectrum Competition, etc.
- The RFI Disruption Risk Can Be Reduced to Acceptable Levels

LAAS Overview

- Ground-Based Augmentation System (GBAS)
- Projected Primary System for Category I – IIIb
  - Positioning Service
  - (Possible) Surface Movement Ops.
- Three LAAS Segments:
  - GPS Satellites – L1, L2C, L5 GPS Bands
  - LAAS Ground Facility (at the Airports) - LGF
    - L1, L2C, L5, VHF Data Broadcast (108 - 118 MHz)
  - Airborne System – L1 & L5, VDB
- Successful RFI Mitigation is a Key Programmatic Risk
  - Also Must Consider Multipath & Iono Wave Fronts



GPS Satellites
GPS Receiver
VHF Data Broadcast
GPS Receiver
GPS Receiver
VHF Data Broadcast
LAAS Ground Facility
GPS Receiver

LAAS Overview (II)

- The LAAS Ground Facility Provides Augmentations to GPS
  - Corrected Ranging Information
  - Approach Path Data
  - Integrity Information
- Augmentations Enhance “RNP” Parameters (Accuracy, Integrity, Continuity and Availability)

Precision Approach Performance Requirements

Operation	Horizontal Accuracy	Vertical Accuracy	Integrity (Probability of HMI)	Time-to-Alert	Continuity Risk	Availability
GLS/CAT I	16 m	6 m to 4 m	2×10^{-7}/ approach (150 sec)	6 sec	8×10^{-6}/ 15 sec	0.99 to 0.99999
CAT II and IIIa	6.9 m	2 m	10^{-9}/ 15 sec	1 sec	4×10^{-6}/ 15 sec	0.99 to 0.99999
CAT IIIb	6.2 m	2 m	10^{-9}/ 30 sec (lateral) 10^{-9}/ 15 sec (vertical)	1 sec	2×10^{-6}/ 30 sec (lateral) 2×10^{-6}/ 15 sec (vertical)	0.99 to 0.99999

Source: *Navigation and Landing Transition Strategy*, FAA Office of Architecture and Investment Analysis, August 2002

A Design Challenge – Mitigating RFI Disruptions to an Acceptable Level

- Category II/III (CAT23) is the Focus of This Paper
  - RNP Requirements Are Difficult to Meet
- Dual GNSS Frequency System a Near Certainty for LAAS CAT23
  - L1 and L5 Only Are Allowed in the Aircraft
    - L1, L5 (and VDB) Are in Aeronautically Protected Bands
  - L2C Can Supplement LGF Operations
  - L5 Availability is Years Away (as is Galileo)
- VHF Data Broadcast is Also Subject to RFI
- Reliable Measurement of Iono Anomalies is Difficult

RFI Characterization

- RFI is Classified as Broadband, Narrowband, or Continuous Wave (CW)
  - GPS Band Harmonics are Also an Issue
    - Abetted by Weak GPS Signal at Earth's Surface
- Intentional RFI is a Lower Threat Than Unintentional; It is Less Likely to Occur
  - Presence of Alternate Systems and Procedures Makes Attempts Less Likely
  - Assessment May Change Somewhat When GNSS Become Primary Systems

Intentional RFI

- Jamming
  - Deliberate Broadcast of Signals Designed to Break Code Lock on the GPS Signal
  - Proven Capability for Low-Cost Disruption
  - Rapid Location and Interdiction of Jammers is Difficult
- Spoofing
  - Corruption of Navigation Signal to Cause Path Deviation
  - More Sophisticated than Jamming; No Known Attempts Against Civil Aviation
  - Spoofing is a Serious Military Problem
  - Civil Spoofing Threat is Very Low
    - Also need to spoof the VDB

Unintentional RFI

- Natural Phenomena
  - Ambient Noise, Solar Flares
  - Atmospheric Disruptions
    - Troposphere, Ionosphere
  - Signal Blockage
    - Terrain, Buildings, Foliage
- Human Sources
  - CW Harmonics (In-band, Near-band, Out-of-Band
  - Pulse and Spread Spectrum
    - Ultra Wideband, BlueTooth
  - Leaky Transmitters
  - Transmitters Left On Following Jamming Tests

* * *

Unintentional RFI (II)

- Multipath
  - Navigation Signals That Reflect Off Objects or Terrain Before Reaching Antenna
  - Largest GBAS Error Source
  - Corrupts or Causes Loss of Code Lock
  - Worse When Receiver is Nearer to Ground, or When Tracked Satellite Has Low Mask Angle
  - Introduces Errors in Receiver Code Phase Measurements (Phase, Polarization Changes)
    - Distorts Correlation Function Peak

Unintentional RFI (III)

- Airborne RFI
  - Spurious Emissions Within Cabin
    - VHF Communications Equipment Harmonics
    - PEDs
  - Airborne Sources Much Closer, More Powerful
  - Ground Based Sources
    - VHF Communications
    - TV Station Harmonics

Mitigating the RFI Threat

- Mitigation Classes
  - Redundant and Backup Systems, Procedures
  - Civil GPS Upgrade
  - RFI-Resistant Technology
- Considerations
  - Selected Architecture Must Limit RFI Incidents to Acceptable Levels
  - GPS Backups *Must Always* Be Ready
  - CAT23 Requirements Still Not Validated
- Factors in Mitigation Approach Selection
  - Technology Maturity
  - Benefits vs. Cost
  - Coordination With Requirements Evolution
  - Required vs. Optional Architecture Element

Mitigation in the Design

- Characterize the RFI
  - Necessary in National Airspace System (NAS), & Wherever GBAS is Used
  - Site-Specific Models Needed
    - Need to Locate Interfering Emitters
    - Will Support Requirements Development and System Design & Implementation
- Develop Test Metrics for RFI Mitigation Performance Evaluation
  - For Example, “Anti-Jam” Capability: Ratio of RFI Strength to Signal-in-Space Strength

Mitigation Using Backup Systems

- Backup Classes
  - Operational Contingency
  - Backup System
  - Redundant System
- Inertial Systems
  - Not a Redundant System, but Can Support Precision Approach – Smoothes the GPS Navigation Solution
  - Fully Immune to RFI
  - Desired Performance May Be Expensive to Achieve
    - May Be an Option Only for Some Aircraft
    - Vertical Accuracy Worse than Lateral
- Radar Altimeter
  - Can Augment GBAS or Inertial Vertical Performance
  - Relatively Expensive

Mitigation Using Ground Backups

- Instrument Landing System
  - Primary Precision Approach Aid in the NAS
  - Effective Against RFI
  - No Plans to De-Commission CAT23 ILS
- Surveillance Radar
- LGF With Enhanced RFI Detection Capability

Mitigation Using GNSS Upgrades

- Enhanced GPS Civil Signal Power
- Dual Frequency (and More)
  - Second Civil Aeronautical Band Signal (L5)
  - Another New Civil Signal (L2C)
    - Possible Operational LGF Role
  - DF Allows
    - Direct Measurement of Iono Delay – A Carrier Tracking Benefit Due to Ambiguity Resolution
    - More RFI Resistance
  - Potential Galileo Role

Mitigation Using Component Technology

- GBAS Receiver Design to RFI Characteristics
  - Spectrum, Power Level, Field Strength, Signal Shape, Polarization, Duration
  - Design Must Address L1, L2C, L5, and VDB Performance
  - Advanced Signal Processing for GBAS
- Antenna Technology
  - Multipath Limiting Antennas (MLA's) and Integrated MLA's to reduce multipath
  - Consider using the WAAS antenna design, if there are performance benefits, and if these antennas can meet other LGF requirements
  - Low gain patterns for anticipated RFI angles, a limited but possible approach for single-element antennas
  - Adaptive, multi-element antennas provide much better performance but are expensive
  - Spatial nulling antennas
  - Gain-producing antennas
- Cockpit Technology – For example, Head-Up Displays

RFI Mitigation Procedures & Policies for CAT23

- Radar Vectoring / Missed Approach
- “Fail-Op” Procedures
- Spectrum Management
- Pilot & Controller Training in Recognizing and Handling RFI Disruptions
- NOTAM Process for Military Jamming Tests

Spoofing & Multipath Mitigation

- Spoofing
  - Radar Surveillance
  - Monitor Flight Path & Waypoint Distance
  - Utilize Ground Proximity Warning Systems, TCAS
- Multipath
  - Ground and airborne multipath model
  - Airframe multipath testing; expensive, but a generic or standard model, if validated, can reduce the expense
  - Observe (and detect) using ranging signal code-carrier phase differences
  - MLA’s & integrated MLA’s (IMLA)
  - Aircraft fuselage and airborne antenna should significantly attenuate ground reflection multipath to extremely small impacts on the airborne system
  - Carrier smoothing can add attenuation, due to aircraft motion over the ground; smoothing the code measurements using carrier phase measurements will reduce multipath error
  - Narrow correlator technology can mitigate both multipath and RFI

Summary

- Many Possible Mitigation Approaches
- Most Will Not be implemented Because of Cost, Performance, Complexity, Compatibility, and Workload Shortfalls
- The Satellite Navigation Community Faces a Difficult, But Achievable Challenge in Applying GNSS to Precision Approach

Background Slides

References

1. RTCA, Inc., “Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment,” RTCA/DO-253A, November 28, 2001.
2. FAA, “Specification: Category I Local Area Augmentation System Ground Facility,” FAA-E-2937A, April 17, 2002.
3. “Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System,” U.S. DOT/Volpe Center, August 29, 2001.
4. DeCleene, B., “Survey of Potential Interference Sources to the Global Navigation Satellite System,” October, 1992.
5. Leiter, M., MITRE, “The Impact of JTIDS/MIDS on Nearby Electromagnetic Equipment,” IADS, May 30, 2001.
6. Murphy, T. and R. Snow, “GPS Multipath on Large Commercial Air Transport Airframes,” Navigation, Vol. 43, No. 4, 1996.
7. FAA Office of Architecture and Investment Analysis, “Navigation and Landing Transition Strategy,” August, 2002.
8. Sklar, J. R., “Interference Mitigation Approaches for the Global Positioning System,” MIT Lincoln Laboratory Journal, Vol. 14, No. 2, 2003.
9. Enge, P., “Local Area Augmentation of GPS for the Precision Approach of Aircraft,” IEEE Proceedings, Vol. 87, No. 1, January, 1999.
10. McGraw, G., et al., “Development of the LAAS Accuracy Models,” ION GPS, September 2000.
11. Misra, et al., “GPS Performance in Navigation,” IEEE Proceedings, Vol. 87, No. 1, January, 1999.
12. Counselman III, C. C., “Multipath-rejecting GPS antennas,” IEEE Proceedings, Vol. 87, No. 1, January, 1999.